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UNDISTURBED SAMPLING OF A CLAY USING VACUUM- AND PISTON-TYPE SAMPLERS

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

June 1950

CORPS OF ENGINEERS, U. S. ARMY

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TECHNICAL MEMORANDUM NO. 3-315

WATERWAYS EXPERIMENT STATION

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PREFACE

This investigation was authorized in the 1st indorsement to a memorandum from the Waterways Experiment Station to the President, Mississippi River Commission, dated 12 May 1947, subject, "Special Projects for Fiscal Year 1948."

Personnel of the Embankment and Foundation Branch of the Soils Division, Waterways Experiment Station, conducted the study. Engineers connected with the study were Messrs. W. J. Turnbull, S. J. Johnson, A. A. Maxwell, T. B. Goode, and W. M. Mullinnix. This report was prepared by Mr. Mullinnix.

CONTENTS

UNDISTURBED SAMPLING OF A CLAY USING VACUUM- AND PISTON-TYPE SAMPLERS

PART I: INTRODUCTION

1. Various tests are performed on soil samples during an investigation for an engineering project. For some tests the type of sample is of little importance, but for tests to determine strength and consolidation characteristics of the soil, factors upon which the design of a structure may be based, it is very important to have samples as nearly like the material in situ as possible. Some disturbance to the sample is inevitable during the sampling process, the degree of disturbance depending upon the type of material, the equipment, and the method used in obtaining the sample.

2. The purpose of the investigation reported herein was to determine the field performance of several types of undisturbed sampling devices in sampling a typical clay encountered in the alluvial valley of the lower Mississippi River, and to evaluate their performance by means of laboratory tests made to determine the type and degree of sample disturbance caused by the various sampling procedures. The investigation made to accomplish this purpose consisted of the following:

- a. Field boring program to obtain samples of a fairly homogeneous material using different types of sampling devices.
- b. Laboratory testing program to determine the sample disturbance caused by the various sampling devices.
- c. An analysis of the test data to determine, if possible, the degree and type of disturbance caused by the samplers.

Types and Causes of Sample Disturbance

3. Sample disturbance has been discussed at length by Hvorslev[1]* and others and will not be covered in detail in this report. According to Hvorslev, sample disturbance can be divided into the following basic types:

- a. Changes in stress conditions,
- b. Changes in water content or void ratio,
- c. Disturbance of the soil structure,
- d. Changes in thickness of the soil layers,
- e. Mixing of the soil layers.

These types of disturbance are listed approximately in decreasing order of their occurrence.

4. In the best undisturbed samples obtained, samples carefully cut by hand from test pits, some disturbance to the natural structure is inevitable, due solely to the change in stress condition caused by removal of the overlying and surrounding soil. The type and degree of additional disturbance in samples obtained from borings will very with the type of sampling equipment, the methods used in sampling, the type of material being sampled, and the care with which the samples are handled after they are obtained.

5. In this investigation the depths to which it was desired to obtain soil samples were too great to permit obtaining "control" samples by means of test pits due to the excessive cost which would be involved. Therefore, sample disturbance was evaluated on a comparative basis between the various sampling methods used by means of examinations and laboratory tests on the soil as described later.

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* Numbers refer to publications listed in the bibliography.

PART II: SAMPLING DEVICES AND METHODS

Vacuum-type Sampler

6. The vacuum-type sampler (fig. 1) has an air-hose connection in the sampler head so that a vacuum or pressure can be applied to the device during the sampling operation. The sampling tube proper is made of thin-walled seamless tubing. A rubber gasket between the tube and sampler head insures an airtight connection.

7. The sampler head is connected to a pressure-vacuum pump during the sampling operation. A steady supply of air is pumped into the sampler as it is lowered into the boring. This air pressure keeps water or extraneous matter out of the sampler until the bottom of the sampling tube comes in contact with the bottom of the boring. The air pressure is then released and the sampling tube driven into the soil by means of a hydraulic ram on the drill rig. A vacuum is applied to the top of the sampler to overcome the vacuum at the lower end of the sample caused by withdrawal, and the sample is withdrawn from the boring. The sampling tube is then removed from the head, the sample ejected from the tube by means of a screw-jack ejector and sealed in paraffin in a cardboard container.

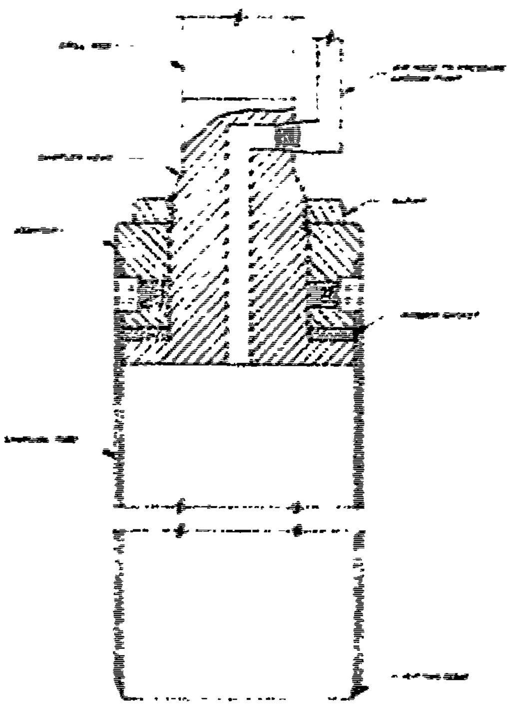


Fig. 1. Vacuum-type sampler

Piston-type Sampler (5-in. Diameter)

[illegible]. A schematic drawing of the piston-type sampler is shown by figure 2. The principal feature of this type of sampler is a piston that works inside the sampler tube. The piston is controlled by a piston rod extending up through the drill rod. At the start of the sampling operation the piston is set flush with the bottom of the sampler and the sampler lowered into the boring. When the sampling tube touches the bottom of the boring, the piston rod is fastened securely so that the piston will remain stationary during the sampler drive. The sampling tube is then driven into the soil at a steady rate of approximately 1/2 ft per sec. In the tests reported herein in which the 5-in-diameter piston-type sampler was used, the length of drive was about 5 ft, and it was necessary to drive the sampler by means of a cable drawdown arrangement as the length of drive of the hydraulic ram was only 30 in. After the sampling tube has been driven into the soil, the piston is released and the downward movement, if any, observed. The amount of movement is recorded and from this the per cent recovery can be computed. The piston is then locked into position and the sampler removed from the boring. The sample is removed

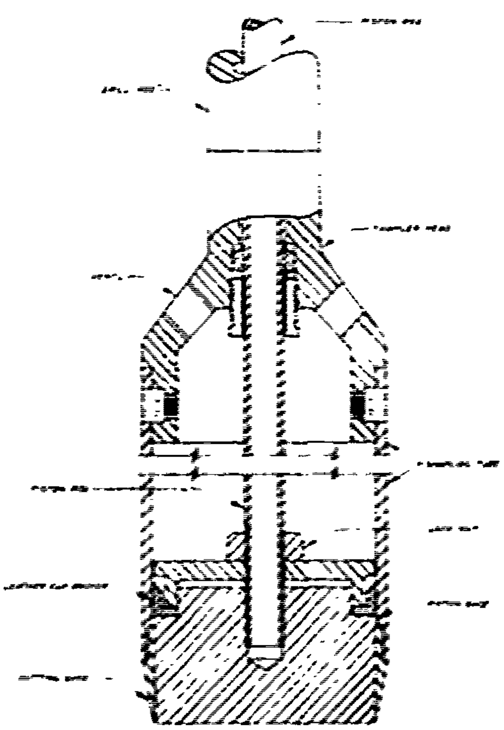


Fig. 2. Piston-type sampler

from the tube by means of a screw-jack ejector and sealed in paraffin in cardboard containers.

Piston-type Sampler (2.87-in. Diameter)

9. This sampler is similar to the sampler described in the preceding paragraph, except that the diameter is 2.87 in. instead of 5 in. When this 2.87-in.-diameter sampler is used samples are not taken in lengths greater than about 2.2 ft due to the difficulty of removing the sample from the tube.

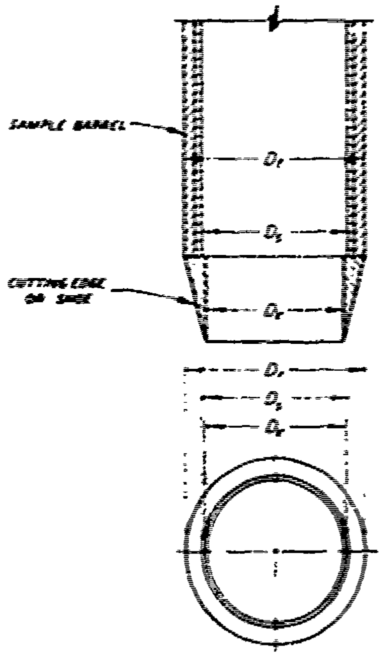
5-in.-piston-type Sampler With Liners

10. This type of sampler is essentially the same as the 5-in. ID piston type and the sampling procedure is the same. The principal difference is the use of thin-walled metal sectional liners in the sampling tube. These liners are in 1-ft sections and are held together by metal bands. After removal from the sampling tube, the bands are slipped past the joints and the 1-ft sections separated by cutting through the soil at the joints with a fine steel wire.

Sampler Dimensions

11. The piston samplers are equipped with removable cutting shoes having sharpened, tapered cutting edges, while the vacuum sampler has the thin-walled sampling tube beveled and drawn in to form a cutting edge. The dimensions of the cutting edges are usually varied, depending on the type of soil being sampled. It is desirable to have a cutting edge which will provide sufficient inside clearance to reduce the inside wall

friction as much as possible. However, there should be enough inside wall friction to retain the sample during withdrawal from the boring. In general, most samplers are equipped with cutting edges that provide inside clearances ranging from approximately 1 to 3.5 per cent. Dimensions of the sampling tubes and cutting edges are shown on figure 3. Also given on this figure are definitions of area ratio and inside clearance, factors which influence greatly the performance of a sampling tool.



$$\text{Inside Clearance} = \frac{D_s - D_e}{D_e}\,100\%$$

$$\text{Area Ratio} = \frac{D_t^2 - D_e^2}{D_e^2}\,100\%$$

CHARACTERISTIC DIMENSIONS, CLEARANCES AND AREA RATIOS OF SAMPLERS

TYPE SAMPLER	NET LENGTH OF SAMPLE TUBE FEET	OUTSIDE DIA. OF SAMPLER INCHES D_t	INSIDE DIA. OF SAMPLER INCHES D_s	INSIDE DIA. OF CUTTING EDGE-INCHES D_e	INSIDE CLEARANCE %	AREA RATIO %
PISTON, WITH SECTIONAL LINERS	6.0	5.25	4.79	4.70 4.72 4.74	1.91 1.48 1.05	24.8 23.7 22.7
PISTON	4.0	5.25	5.00	4.84 4.87	3.3 2.67	17.6 16.2
PISTON	3.1	3.00	2.875	2.83 2.85	1.59 0.88	12.4 10.8
VACUUM	1.5-2.0	5.25	5.00	4.865 4.920 4.930 4.950 4.970	2.77 1.63 1.42 1.0 0.64	16.4 13.9 13.4 12.5 11.4

Fig. 3. Dimensions, clearances, and area ratios of samplers

PART III: BORING PROGRAM

Site Description

12. The field work was conducted in the Mississippi Alluvial Valley at the upper end of the Morganza Floodway in southern Louisiana. Previous exploratory borings made in connection with studies for location of the floodway control structure showed that the soil at this site consisted of a deep stratum of predominantly clay material and appeared to be fairly homogeneous. The soil may be classified as backswamp materials, except the upper 10 ft of sandy silts and clay silts, which are evidently more recent natural levee deposits. A second group of borings was later made at a site about one mile from the first site. Limited laboratory tests were performed on the samples obtained from these borings but the results were essentially the same as hereafter discussed for the first group and are not included in this report.

Description of Field Operations

13. Four borings were made as shown on figure 4. Three of the borings were drilled to a depth of approximately 50 ft and the fourth to a depth of approximately 45 ft. Undisturbed samples were obtained at various depths using different types of samplers. It was believed that samples from the same elevation in such closely spaced holes would have similar soil characteristics and that a comparison could be made of the effect of the different sampling devices on the samples. Figure 4 shows the location plan and profiles of the borings and the types of samplers

used. Also shown on the figure are pertinent dimensions of the samplers and the approximate lengths of drive.

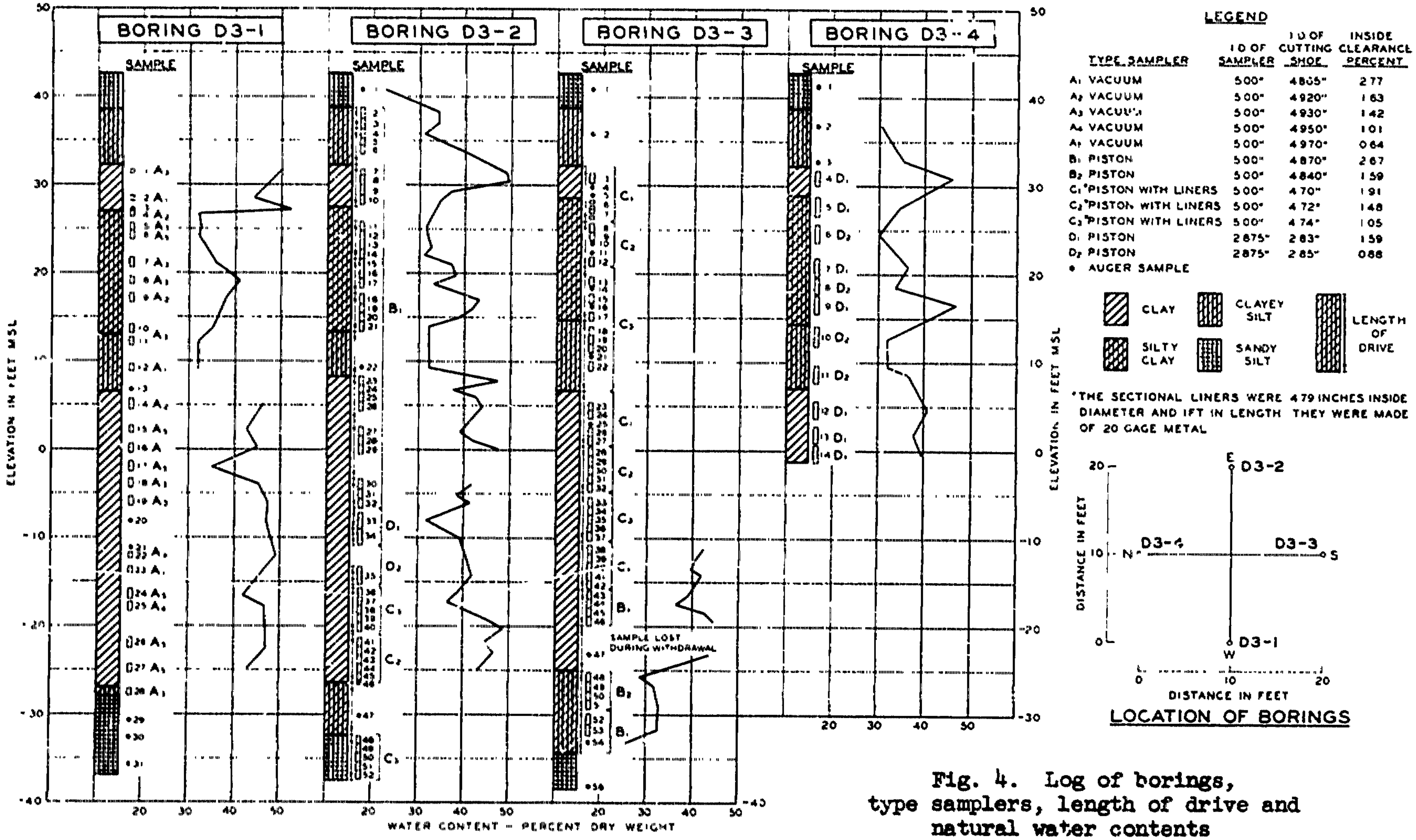


Fig. 4. Log of borings, type samplers, length of drive and natural water contents

PART IV: LABORATORY INVESTIGATION

Detection of Disturbance

14. The various tests used to detect sample disturbance are discussed in the following paragraphs.

Visual determination

15. Distortion or mixing of soil layers can sometimes be observed by slicing a sample, providing the sample has a definite structural pattern such as parallel strata of varying types or characteristics. If the stratifications are not discernible when the sample is freshly sliced, their visibility may be increased by allowing the sample to air dry.[2] The coarser soil layers will dry faster and as the water content of these layers approaches the shrinkage limit the color contrast will reach a maximum. At this point any distorted or disturbed sections may generally be observed and a permanent record obtained by photographing.

Unconfined compression test

16. The unconfined compression test has been used successfully[3] to detect sample disturbance. It has been found that disturbance generally causes a decrease in the maximum shearing strength of the soil and also causes a decrease in the initial slope of the stress-strain curve, as well as exhibiting a more rounded curve shape as compared to the relatively sharp peak for some undisturbed soils. These effects are illustrated by a hypothetical case as shown on the upper plot of figure 5. It was believed that unconfined compression tests would yield data for comparing samples taken with different sampling devices.

Consolidation test

17. It has been found that sample disturbance or remolding tends to lower the void ratio-pressure curve and the preconsolidation pressure as determined from the consolidation test.[3] In the case of complete remolding, the void ratio-pressure curve is so rounded that it is difficult to determine the previous stress history of the sample with any degree of accuracy. Figure 5 shows the typical effect of remolding a clay soil.

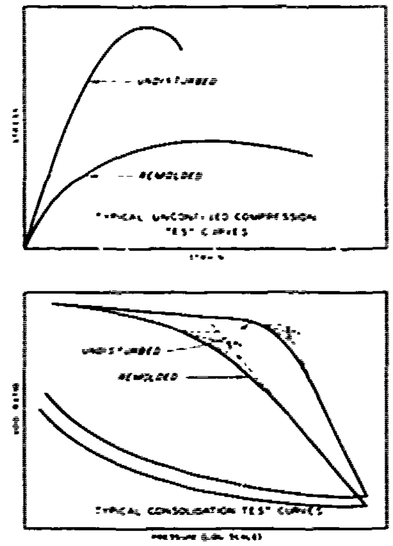


Fig. 5. Typical effect of remol .ng on strength and consolidation characteristics of a sensitive clay soil

Classification tests

18. Mechanical analyses, water contents, and Atterberg limits tests were performed on samples selected for detailed testing and on other samples for the purpose of comparing sample characteristics. A summary of classification data is included in table 1. A log of borings showing the classifications and water contents of the materials is given on figure 4.

Location of Disturbance in Long Samples

19. In this phase of the laboratory program tests were performed on soils obtained in one continuous drive of the sampler to determine the amount and location of the disturbance which might occur in a sample approximately 5 ft in length. It was believed that most of the disturbance, if present, would occur near the top and bottom of a long sample

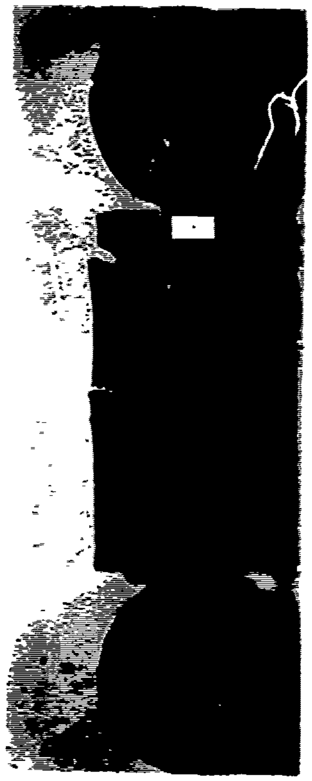
and that the material in the center would be less disturbed.

Initial tests

20. Samples 36, 37, 38, 39, and 40 of boring D3-2 were selected for the initial tests. These samples were all obtained in one 5-ft drive using a 5-in.-diameter piston-type sampler with 1-ft sectional liners. A cutting shoe with an inside diameter of 4.74 in., and providing an inside clearance of 1.05 per cent, was used.

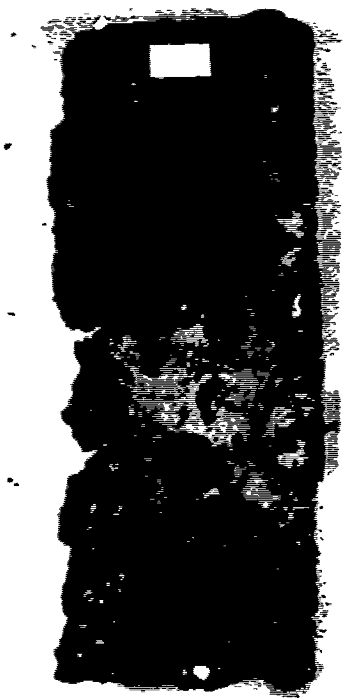
21. Sliced specimens. Horizontal slices 3/4 in. thick were taken from the top and bottom of the samples and vertical slices 3/4 in. thick and 4 to 11 in. long were taken from the center of the samples. These slices were permitted to air dry in an attempt to bring out any visible evidence of disturbance or distortion of the soil due to sampling. Photographs of the slices (fig. 6) show that the soil has a mottled or marbled appearance with no definite structural pattern; thus, no visible signs of disturbance could be noted. The cracks visible in the samples were due to shrinkage that occurred as the samples dried out and were not present in the samples when freshly sliced.

22. Unconfined compression tests. Unconfined compression tests were performed in duplicate on the top, middle, and bottom portions of samples 36, 37, 39, and 40. Test results are shown in table 2 and on figures 7, 8, 9, and 10. Inspection of the data shows that the strengths of samples from the same elevation within the specimen are not in very good agreement. These differences, in part, may be attributed to variations in water content and density and to minor changes in composition of the soil. It will be noted on the figures that all of the stress-strain curves except two (sample 40) show a well-defined peak usually

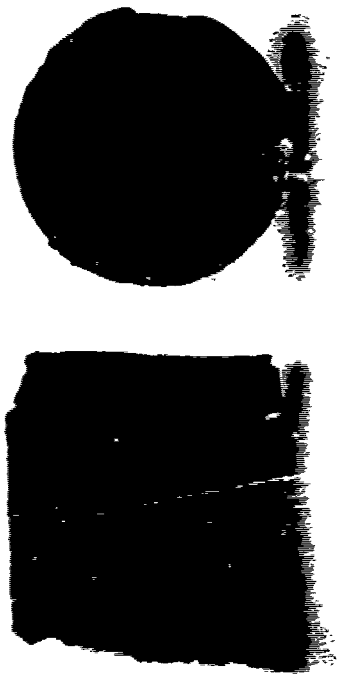


Sample 36

Sample 37



Sample 38



Sample 40

Fig. 6. Photographs of sliced samples -- boring [illegible]

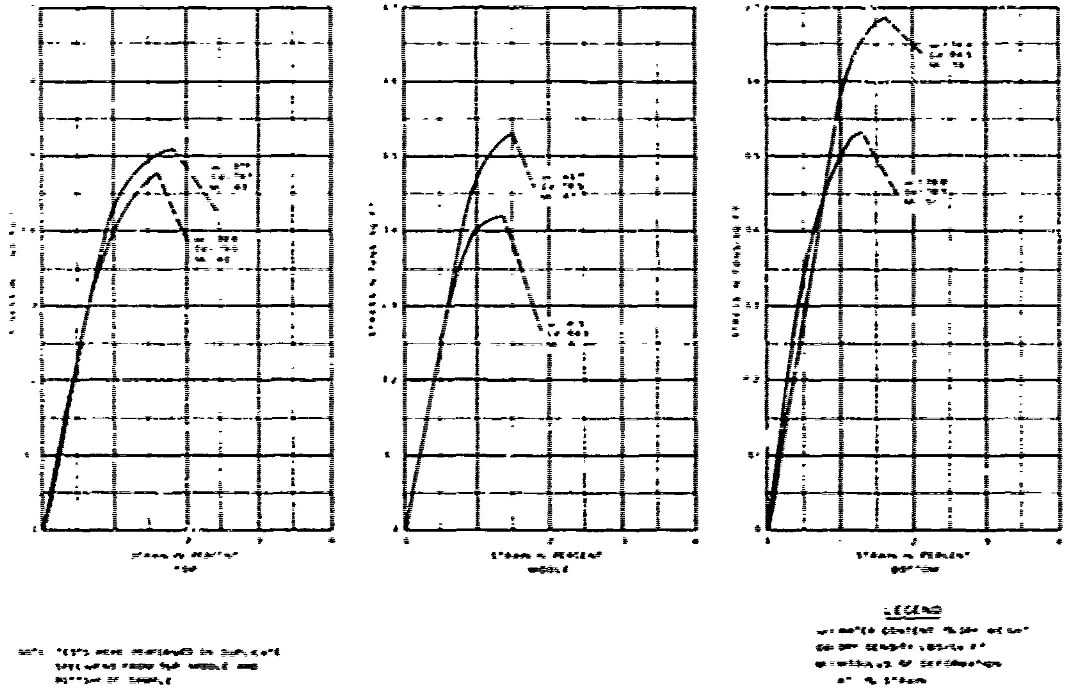


Fig. 7. Unconfined compression tests, boring D3-2, sample 36

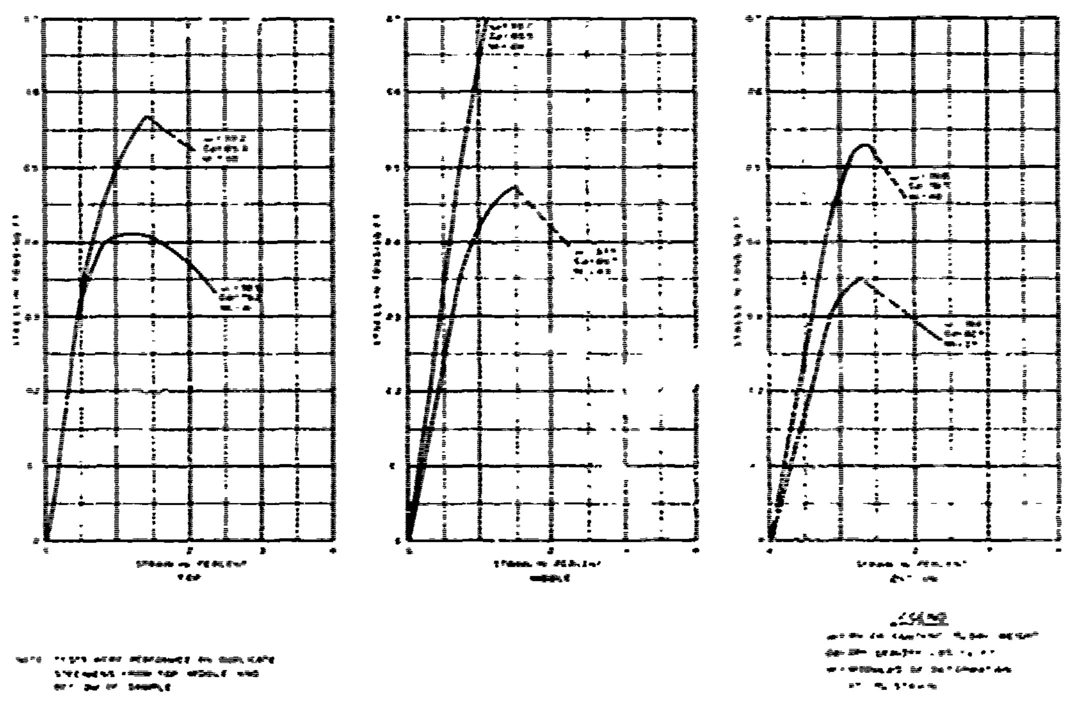


Fig. 8. Unconfined compression tests, boring D3-2, sample 37

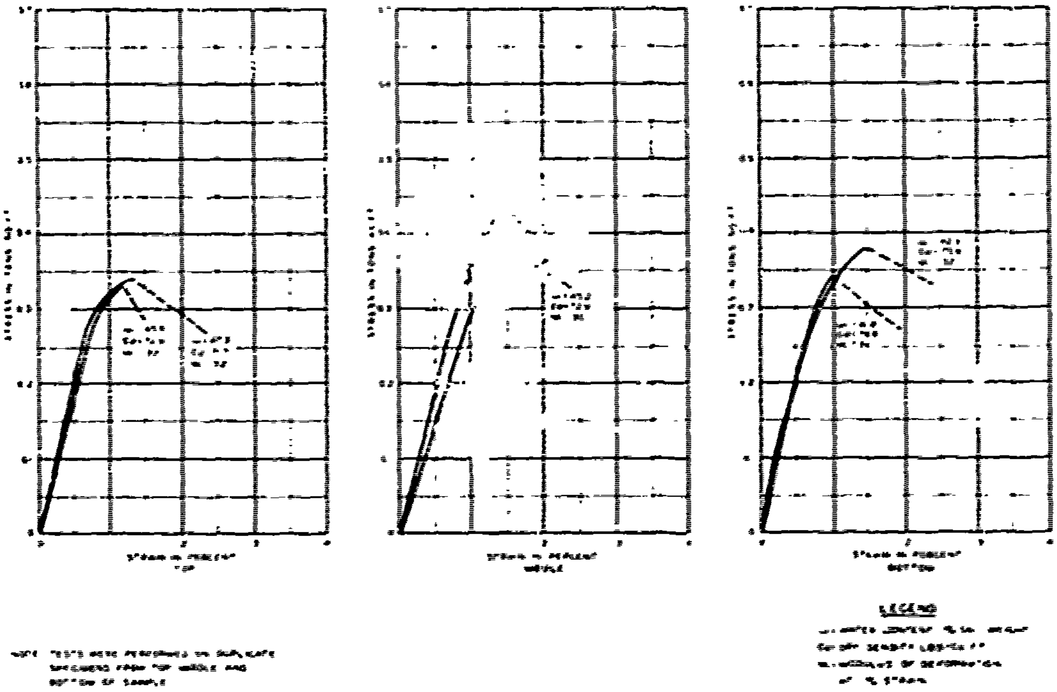


Fig. 9. Unconfined compression tests, boring D3-2, sample 39

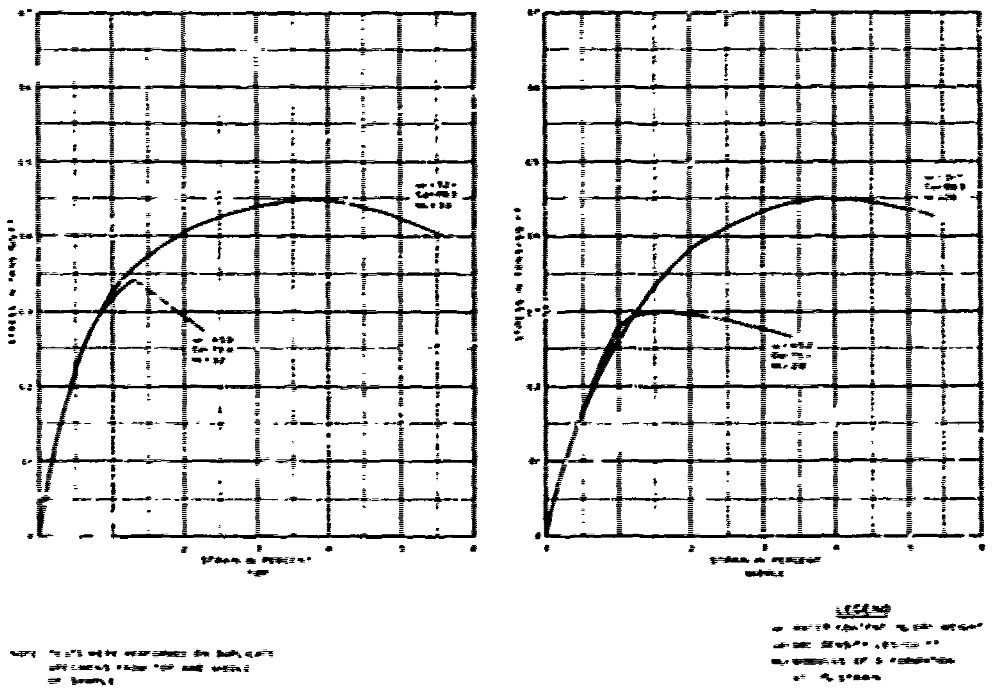


Fig. 10. Unconfined compression tests, boring D3-2, sample 40

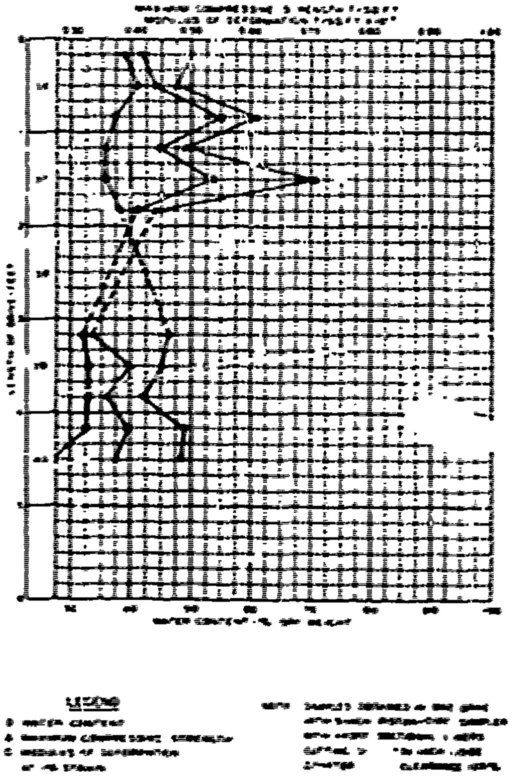


Fig. 11. Variation in water content, maximum compressive strength and modulus of deformation boring D3-2, samples 36-40

associated with undisturbed materials. The two exceptions in sample 40 show a very round stress-strain curve, indicating a bulge-type failure similar to curves obtained from remolded or disturbed materials. The adjacent "duplicate" samples show a reasonably sharp break at the peak of the stress-strain curve but the soil may be substantially different since the water contents are about 6 per cent less. The variations in compressive strength and average water content throughout the length of drive are shown on figure 11. The maximum strength value occurs at the middle of sample 37 which is the second sample of the drive. Below this point the strength values show a general decrease with the lower values occurring in samples 39 and 40. These latter samples had a water content range of 42 to 49 per cent as compared to a range of 35 to 41 per cent for samples 36 and 37, which could readily account for the variations in strength shown. An attempt was made to correlate the natural water content with maximum compressive strengths (see Fig. 12). It may be seen that the compressive strength decreases in a general way with increasing water content when all test points are considered. When the test points are considered with respect to their position in the total sample, however,

they are scattered and no consistent trend is apparent. This is believed to be partly due to rapid variations in water content and density both vertically and horizontally and partly due to the structure of the material, as will be discussed in more detail later. Because of these variations in the properties of the soil the test data were not, therefore, conclusive as to whether any part of the difference in strength values was due to sample disturbance or to the variation in the natural water content and density, although the latter consideration appears the more probable.

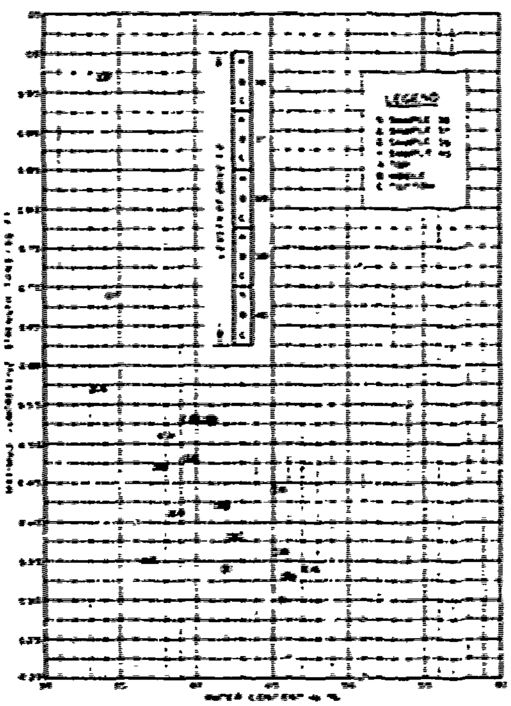


Fig. 12. Maximum compressive strength vs water content boring HB-2

23. Modulus of deformation. An attempt to correlate the natural water content with modulus of deformation was also made. The modulus of deformation is defined as the ratio between the stress and strain, and in this report the stress at one per cent strain was selected arbitrarily. Since this value approximates the slope of the stress-strain curve, it was reasoned that comparatively lower values of the modulus of deformation would reflect a flatter curve and thus be indicative of possible sample disturbance (see fig. 5). The variation of modulus of deformation throughout the length of drive is shown on figure 11. The lowest values of modulus occur in samples 39 and 40, at the bottom of the drive, but

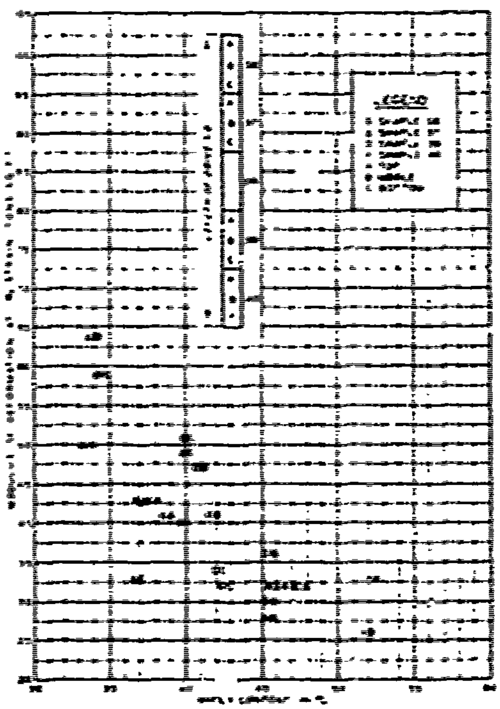


Fig. 13. Modulus of deformation at 1 per cent strain vs water content, boring D3-2

as discussed above for compressive strength, the lower values are probably due to increased water contents. Figure 13 shows a plot of water content versus modulus of deformation. Again it can be noted that a trend for decreasing modulus with increasing water content exists when all the test points are considered, but when the individual values are considered with respect to their position in the total sample, no trend is apparent which could be used to indicate sample disturbance as discussed above.

Additional tests

24. Inasmuch as the results of the initial tests performed on samples of one drive were inconclusive, it was considered necessary to perform tests on additional samples in an effort to determine the amount of disturbance occurring within a long sample. For these additional tests, samples 41-45 of boring D3-2 and samples 38-42 of boring D3-3 were selected. Each group of samples was taken in one 5-ft drive using a 5-in. piston-type sampler with 1-ft sectional liners. However, cutting shoes with different inside diameters were used in each case. The first group of samples was obtained with a cutting shoe providing an inside clearance of 1.40 per cent; in the latter group the cutting shoe provided an inside clearance of 1.31 per cent.

25. Sliced specimens. Selected samples from each drive were sliced and permitted to air dry using the procedure previously outlined. The samples, very similar to those shown in figure 6, also showed a mottled or marbled appearance. No visible disturbance or distortion of the soil was evident.

26. Unconfined compression tests. Unconfined compression tests were performed in duplicate from the top, center, and bottom of samples from each drive. Test results and other pertinent data are shown in table 3. As in the initial series of tests there was no consistent variation shown by the strength values; in some cases the samples from the top and bottom of the drive showed higher strength values than the samples from the center. Attempts were again made to correlate the natural water content with the maximum compressive strength and with the modulus of deformation at one per cent strain, and while trends as noted earlier

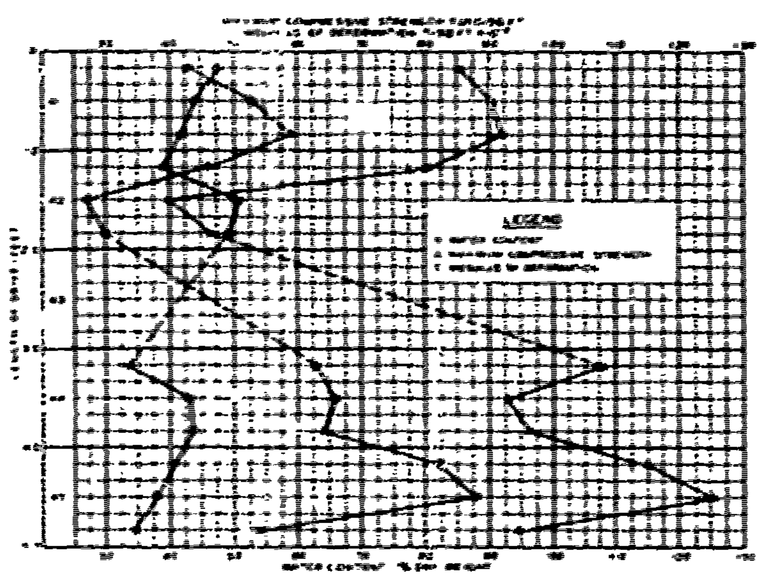


Fig. 14. Variation of water content, maximum compressive strength and modulus of deformation, boring D3-2, samples 41-45

were apparent, no variation of strength with respect to the location of the test specimen within the sampler was apparent. Figures 14 and 15 show the variation in water content and strength values throughout each drive. From figure 14 it can be seen that the average water content and strength values varied considerably. There is a trend for the strength values to vary inversely with the water content but there is no other consistent trend evident that can be attributed to sampler disturbance. A somewhat better idea of the very rapid changes in water content and density can be obtained from a study of table 3; this table reveals that the adjacent samples differed in water content by as much as 17 per cent in one instance. The samples from boring D3-3, shown by figure 15, show a fairly uniform average water content throughout the length of drive, however, there is considerable variation in the strength values, with the maximum values occurring near the top and bottom of the drive. The water content and density of individual samples varied much faster than is indicated by figure 15 as can be seen from the test results shown in table 3.

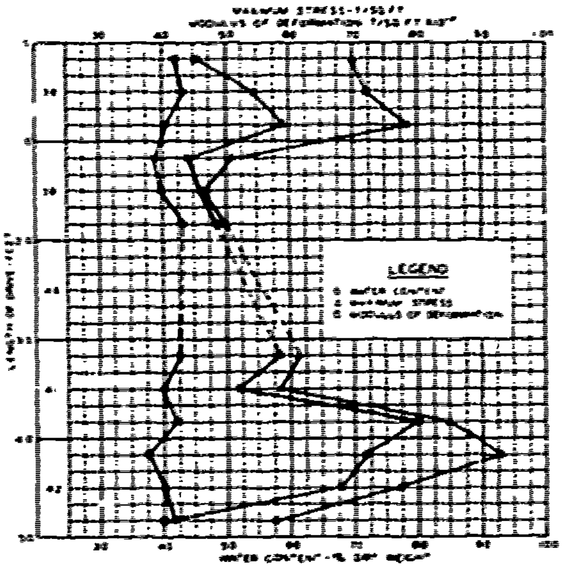


Fig. 15. Variation of water content, maximum stress and modulus of deformation, boring D3-3, samples 38-42

Discussion

27. The data presented in the preceding paragraphs are the results of tests performed on samples obtained with the 5-in. piston sampler with

liners. It was the purpose of these data to determine where the most disturbance would occur in long-drive samples and how serious such disturbance might be. However, due to the rapid and inconsistent variation in water content and strength values, it could not be definitely concluded as to whether any disturbance occurred or whether the natural variation in soil characteristics accounted for all of the variation in strength properties.

Consolidation Tests

28. The results of the unconfined compression tests demonstrated that this test was unsatisfactory for indicating any difference in disturbance caused by the various samplers on the particular soil sampled. It was therefore decided to attempt such a comparison by performing consolidation tests on selected samples taken with different samplers to determine if any differences existed in the indicated preconsolidation pressures (see paragraph 17 and figure 5). The results of the consolidation tests together with the classification data are presented in table 4. The estimated preconsolidation pressure for each sample was determined[3], and these values and present overburden pressures are shown by figure 16. In all cases the present overburden pressure is less than the preconsolidation pressures. This indicates that the soil has, at some time in the past, been subjected to greater stresses than now exist, probably due to alternate wetting and drying of the layers as the deposit built up. Figure 16 indicates that considerable differences exist in the preconsolidation pressures of the samples taken with the different samplers. Because of the rounded shape of most of the void ratio-pressure

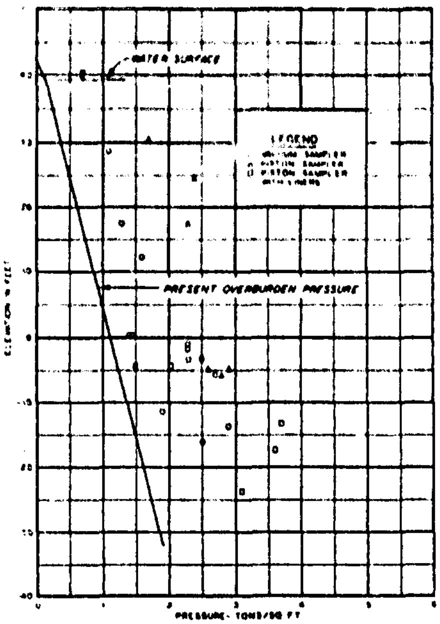


Fig. 16. Comparison of present overburden pressure and preconsolidation pressures

curves, it was difficult to determine the preconsolidation pressure with accuracy. The samples obtained with the vacuum sampler show, in general, a lower preconsolidation pressure than the samples obtained with the piston samplers. This trend is particularly evident in the upper portion of the borings throughout the depths investigated and could possibly indicate that more disturbance was caused by the vacuum sampler.

29. The 5-in. piston sampler has a cutting shoe which provided an inside clearance of 2.67 per cent, whereas the vacuum samples were obtained with cutting shoes providing inside clearances ranging from 0.64 per cent to 2.77 per cent (see table 4). The 5-in. piston sampler with liners had cutting shoes providing inside clearances of 1.48, 1.91, and 2.67 per cent. The samples obtained with the 1.91 and 2.67 per cent inside clearances showed higher values for the preconsolidation pressures. These data tend to indicate that the higher percentage of inside clearance causes less sample disturbance in the type of soil encountered in this investigation.

Analysis of Data

30. Data obtained from the preceding tests were generally inconclusive and it is believed that natural variations in the soil were

responsible for most of the inconsistent test results. Consideration was also given to the fact that perhaps the type of soil used in this investigation was of a low sensitivity and any disturbance might not be apparent in the test results. For this reason, additional tests were performed to determine the variation in the moisture content and density and to determine the degree of sensitivity.

Moisture content and density

31. Samples 35 and 37 from boring D3-3 were selected for detailed moisture-content determinations. To obtain a complete horizontal and vertical pattern of the moisture content, the samples were sliced into 12 horizontal sections 1 in. thick, and five moisture-content determinations were made from each section. The results are shown on figure 17 which demonstrates that considerable variation occurred in both horizontal and vertical directions, with as much as 15 per cent variation on the same horizontal plane within a 5-in.-diameter sample. Since the samples were almost completely saturated, variation in water content indicates a corresponding variation in density. Such variations could account for a large part and perhaps all of the variations in strength noted previously.

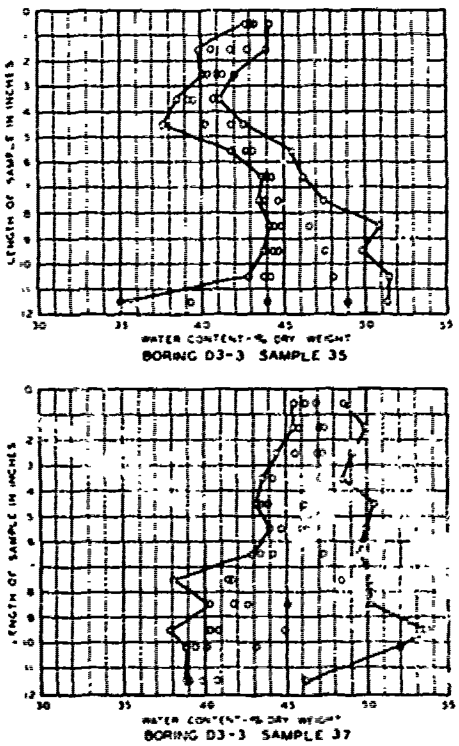


Fig. 17. Variation of moisture within samples

Sensitivity of clay

32. Terzaghi and Peck[4] state that, "The term sensitivity indicates the effect of remolding on the consistency of a clay, regardless of the physical nature of the causes of the change. The degree of sensitivity is different for different clays, and it may also be different for the same clay at different water contents." They also express the degree of sensitivity, S_t, of a clay as, "The ratio between the unconfined compressive strength of an undisturbed specimen and the strength of the same specimen at the same water content but in a remolded state. The values of S_t for most clays range between 2 and about 4. For sensitive clays they may range from 4 to 8." To determine the degree of sensitivity of the clays studied in this investigation, unconfined compression tests were performed on samples selected from approximately the same elevation. The samples tested were sample 16 from boring D3-1, sample 32 from boring D3-2, and sample 32 from boring D3-3. The samples were obtained with the vacuum sampler, the 5-in. piston sampler, and the 5-in. piston sampler with sectional liners, respectively.

33. The samples were sliced horizontally into four sections and the two upper sections were used for unconfined compression tests. Three 1-in. undisturbed specimens were obtained from each of the two sections and the remaining material was remolded to as nearly the same water content as practicable. Two remolded specimens were obtained from each section. The results of tests on undisturbed and remolded specimens are summarized in table 5. Typical stress-strain curves are shown by figure 18. The compressive strengths of the remolded specimens were equal to or greater than the strength values of the undisturbed specimens in the

majority of cases. Thus it is apparent that the change in structure induced by remolding the soil did not decrease its compressive strength. In all cases the remolded specimens showed a higher per cent strain at the point of maximum stress, which indicates that the change in structure due to remolding makes the material become more plastic. The degree of sensitivity ranged in value from 0.60 to 1.12, with an average value of 0.85, indicating that the strength of the material is not sensitive to remolding and that any partial sample disturbance due to sampling probably would not be evident in the results of laboratory strength tests.

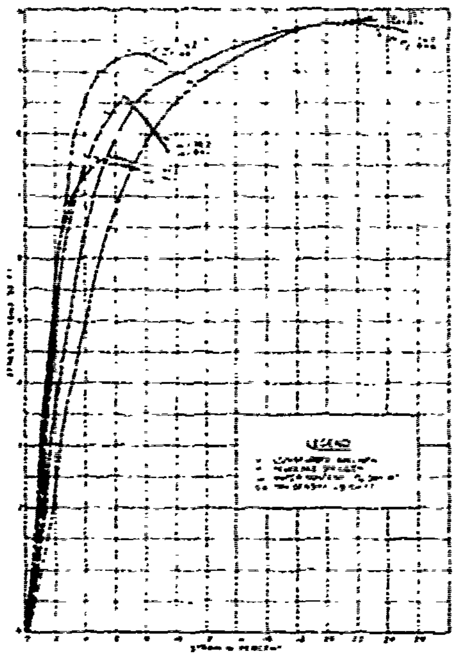


Fig. 18. Unconfined compression test, boring D3-2, sample 32, section B

PART V: GENERAL DISCUSSION

34. The results of visual examination of sliced samples of soils in this investigation showed the material to have no definite visible structural pattern. Thus, this method could not be used to determine the amount of sample disturbance in the various sampling procedures. Unconfined compression tests showed considerable variations in compressive strength of soils which are attributed largely to variations in water content, density, and soil characteristics. There was no conclusive evidence from these tests to indicate whether or not the soil had been disturbed in sampling. Later tests showed that the soil under investigation was a nonsensitive clay, thus the results of the unconfined compression tests would not be expected to be indicative of disturbance of the soil. The results of consolidation tests showed, by comparison of preconsolidation loads, that there was a tendency for more disturbance to be caused by the vacuum sampler than by the piston sampler. These data also indicated that higher percentages of inside clearance in the sample tube caused less sample disturbance in the soil encountered in this investigation.

35. Probably the most significant feature disclosed by this investigation is the lack of sensitivity of this type clay to remolding. The practical value of this rather detailed investigation is that where information as to the strength of this type of material is desired samples may be obtained by any one of the samplers described herein with satisfactory results, although the sampler should be selected on the basis of ease and economy of operation. The test data indicate that the

more advanced type of sampler, which is the piston sampler, gives better results where information on the consolidation characteristics of a soil is desired.

36. The lack of sensitivity of this clay is due apparently to the manner in which the deposit is formed. Judging from the known geological history of the area, and the appearance of the samples, it is likely that the materials were deposited each year by an overflow of the river and that the material so deposited dried out and cracked during the low-water season. This type of formation would explain satisfactorily the results of the consolidation tests reported herein where the indicated preconsolidation loads are consistently greater than the overburden pressure.

37. Where the soil has been deposited under water and generally remained under water, as in abandoned channel fillings, the above type of structure does not develop and it is known that the material does exhibit marked sensitivity and that the preconsolidation load from the laboratory tests is about the same order of magnitude or less than the overburden pressure.

38. The preceding considerations relative to the formation and properties of these two types of materials suggest that field exploration programs should be conducted in such a way that the properties of the soils being sampled are recognized and taken into account. Thus, if the soil being sampled is of a mottled appearance and is located in a backswamp region, judgment and possibly a few tests might be sufficient to determine that, if the primary purpose of sampling is to furnish strength data, only average care in sampling is required and the sampler

used should be one which is economical to operate. On the other hand, if the soil deposit does not exhibit a mottled appearance but is uniform and sensitive to simple remolding tests by hand, then considerable care and the best sampling equipment and techniques should be employed in obtaining undisturbed samples. At this time it is believed that the most suitable sampler for work in the last category is the piston sampler when operated with a fixed-type piston.

39. It is known that in some areas of the alluvial valley the clays found are insensitive, and it appears probable that these areas are generally in backswamp deposits. It cannot be assumed that the clays in all backswamp deposits are insensitive, however, since in some low areas the material deposited during flood stage may have been submerged practically all the time so that a sensitive structure has been developed. It appears reasonable that observation of the nature of soil deposits in various parts of the alluvial valley, together with detailed data on the geology, may permit mapping of areas where the soils are insensitive and where particular care is not required in obtaining undisturbed samples. By the same approach it might be possible to map areas which are known to contain sensitive deposits. At this time it appears that abandoned channel fillings will usually contain sensitive clays, but it is possible that certain backswamp areas, as discussed above, will also contain this type of material.

40. Mapping of soil types as regards sensitivity to remolding, in addition to serving as a guide in the conduct of soil exploration in the field, might also be of considerable aid in another way in levee construction and in other design and construction problems. If a soil is sensitive

to disturbance caused by sampling operations, it will be true generally that after the maximum strength has been reached the strength will decrease substantially with further strain. On the other hand, for an insensitive material the maximum strength is maintained practically regardless of further movement of the soil. In the design of levee foundations it is commonly assumed and accepted that the soil will be overstressed at some points before it has been stressed to maximum strength at others, but that with continued yielding a condition is reached wherein the maximum strength of the soil is attained at all points. It is obvious that if the soil is insensitive to remolding the strength reached at failure will be the same at all points and will equal the maximum strength of the soil, and for this condition the strength indicated by laboratory tests can be relied upon and a moderate factor of safety employed. However, if a soil is sensitive to strain, at the time of failure in the field some parts of the soil would have been strained considerably more than other parts, with the result that the maximum strength will be mobilized at some points; but, due to greater strains at other points, the strength will be less. Under these circumstances, reliance upon full strength of the soil at all points, as indicated by laboratory tests, would not be conservative and should be recognized in choosing the factor of safety.

PART VI: CONCLUSIONS

41. Analyses of the test results presented in this report indicate the following conclusions. It is emphasized that the conclusions apply only to the type of soil encountered in this investigation.

- a. Disturbance due to sampler or sampling operations tended to be obscured by (1) natural variations in the soil, and (2) by the low degree of sensitivity of the soil.

- b. Based on the results of consolidation tests there was some indication that higher percentages of inside clearance on the cutting shoes caused less sample disturbance.

- c. Results though inconclusive tend to indicate that the piston-type sampler is superior to the vacuum type.

- d. The sensitivity of a clay to remolding should be considered in sampling operations. If a clay is not sensitive only moderate care need be exercised and the sampler used would be the one that is most economical, whereas if a clay is sensitive then the greatest care and the best available sampling equipment should be used. Similarly, a knowledge of clay sensitivity will permit more intelligent design assumptions on certain types of projects.

BIBLIOGRAPHY

1. Hvorslev, M. J. The Present Status of the Art of Obtaining Undisturbed Samples of Soils. Preliminary draft of report of Committee on Sampling and Testing, American Society of Civil Engineers, March 1940.

   ______________ Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes. New York: The Engineering Foundation, November 1949. (Preliminary printing for Corps of Engineers by Waterways Experiment Station, Vicksburg, Mississippi. November 1948.)

2. Jurgenson, Leo. "The Shearing Resistance of Soils." Journal, Boston Society of Civil Engineers, vol 21, no. 3 (July 1934), pp 242-275.

3. Casagrande, Arthur. "The Structure of Clay and its Importance in Foundation Engineering." Journal, Boston Society of Civil Engineers, vol 19, no. 4 (April 1932).

   ______________ "The Determination of the Preconsolidation Load and its Practical Significance." Proceedings, International Conference on Soil Mechanics and Foundation Engineering, vol 3 (1936).

4. Terzaghi, Karl and Peck, R. B. Soil Mechanics in Engineering Practice. New York: John Wiley and Sons, 1948.

Table 1

CLASSIFICATION DATA

Boring	Sample	Classification	Mechanical Analysis % Sand	% Silt	% Clay	Atterberg Limits LL	PL	PI	Natural w
D-3-1	2	Clay	6	22	72	73	26	47	35.5
	9	Silty clay	15	50	35	35	12	23	34.2
	11	Sandy silt	22	59	19	30	22	8	28.8
	15					83	32	51	37.5
	16A	Clay	9	28	63	80	23	57	42.3
	B	Clay	9	25	66	84	23	61	45.6
	C	Clay	8	29	63	75	27	48	44.8
	D	Clay	8	21	71	86	26	60	44.8
	17	Silty clay	12	40	48	--	--	--	39.0
	19	Clay	3	30	67	74	23	51	38.5
	22	Clay	2	18	80	70	23	47	40.9
	23	Clay	12	13	75	87	29	58	39.7
	24	Clay	11	24	65	61	28	33	36.6
D-3-2	8	Clay	6	27	67	81	19	62	44.6
	12	Clay silt	24	52	24	46	22	24	27.8
	13	Clay silt				39	24	15	30.6
	18	Silty clay	11	43	46	51	25	26	43.0
	31	Clay	14	29	57	--	--	--	37.8
	32A	Clay	8	23	69	78	25	53	39.7
	B	Clay	8	36	56	72	20	52	35.8
	C&D	Silty clay	13	39	48	60	23	37	38.0

Table 1 (Contd)

CLASSIFICATION DATA

Boring	Sample	Classification	Mechanical Analysis % Sand	% Silt	% Clay	Atterberg Limits LL	PL	PI	Natural w
D-3-2	35	Clay	10	14	76	75	35	40	39.5
	41A	Clay	4	16	80	88	35	53	47.5
	B	Clay	10	18	72	81	31	50	43.9
	C	Clay	3	22	75	71	30	41	41.6
	42A	Clay	7	31	62	67	25	42	34.7-43.1
	B	Clay	10	23	67	73	27	46	59.4-42.1
	C	Clay	6	24	70	82	32	50	42.7-55.7
	43	Clay	11	25	64	70	25	45	37.9
	44A	Clay	10	24	66	73	28	45	33.2
	B	Clay	6	14	80	85	31	54	43.2
	C	Clay	7	23	70	82	27	55	43.8
	45A	Clay	8	19	73	89	29	60	41.0
	B	Clay	10	29	61	71	27	44	38.0
	C	Clay	8	38	54	65	25	40	34.5
D-3-3	32A	Clay	12	28	60	78	24	54	38.4
	B	Clay	7	26	67	81	25	56	40.3
	C	Clay	1	16	83	79	27	52	41.6
	D	Clay	3	19	78	74	27	47	40.5
	35A	Clay	7	12	81	81	28	53	
	B	Clay	7	10	83	80	27	53	
	C	Clay	7	13	80	87	36	51	
	37A	Clay	7	13	80	82	30	52	
	B	Clay	4	19	77	80	34	46	
	C	Clay	4	20	76	74	33	41	
	40	Clay	6	11	83	70	33	37	39.5
	44	Clay	6	22	72	70	28	42	35.9

Table 2

COMPARISON OF UNCONFINED COMPRESSION TEST DATA

Boring L3-2

Sample[1]	Sample Elev msl	Classification	Sample Section	Natural Water Content % Dry Wt	Dry Density Lb/Cu Ft	Unconfined Compression Test Data[2] Max. Stress T/Sq Ft	Strain at Max. Stress %	M_q at 1% Strain T/Sq Ft	Cohesion T/Sq Ft
36	-16.0	Clay	Top	37.7	79.7	0.51	1.8	43	0.25
			Top	39.6	79.0	0.48	1.6	40	0.24
			Middle	41.5	84.3	0.42	1.4	41	0.21
			Middle	40.7	78.5	0.53	1.5	47	0.26
			Bottom	39.8	78.5	0.53	1.3	51	0.26
			Bottom	34.4	84.5	0.69	1.6	59	0.34
37	-17.0	Clay	Top	38.5	79.2	0.41	1.1	41	0.20
			Top	33.2	85.3	0.57	1.4	50	0.28
			Middle	33.7	85.5	0.94	1.8	64	0.46
			Middle	37.5	80.7	0.47	1.5	43	0.23
			Bottom	39.8	79.7	0.53	1.4	49	0.26
			Bottom	36.6	80.7	0.35	1.3	33	0.17
39	-19.0	Clay	Top	47.3	71.7	0.34	1.3	32	0.17
			Top	45.8	72.9	0.33	1.2	32	0.16
			Middle	45.2	72.9	0.36	1.8	30	0.18
			Middle	45.2	73.4	0.44	1.4	36	0.22
			Bottom	41.8	76.6	0.34	1.0	34	0.17
			Bottom	42.3	75.6	0.38	1.8	32	0.19
40	-20.0	Clay	Top	52.1	69.3	0.45	4.0	33	0.22
			Top	45.9	[illegible]	0.34	1.4	[illegible]	0.17
			Middle	51.7	69.3	0.45	3.8	26	0.22
			Middle	45.2	75.1	0.30	1.5	28	0.15

1 Samples obtained in one drive with 5-in. piston sampler with liners.
2 Specimens were 1 in. in diameter and 2 in. high. Tested at rate of strain of 1 per cent per min.

Table 3

CLASSIFICATION AND UNCONFINED COMPRESSION TEST DATA

				Mechanical Analysis			Atterberg Limits						Unconfined Compression Test Data			
Boring	Sample	Sample Elev msl	Classification	% Sand	% Silt	% Clay	LL	PL	PI	Sample Section	Natural Water Content % Dry Wt	Dry Density Lb/Cu Ft	Max. Stress T/Sq Ft	Strain at Max. Stress %	Modulus of Deformation at 1% Strain T/Sq Ft	Cohesion c T/Sq Ft
D-3-2	41	-22	Clay	4	16	80	88	35	53	Top	48.5	72.9	0.79	10.0	46	0.39
										Top	46.4	74.1	0.92	9.0	40	0.46
			Clay	10	18	72	81	31	50	Middle	45.8	74.6	0.78	5.0	48	0.39
										Middle	42.0	78.5	1.03	6.6	58	0.51
			Clay	3	22	75	71	30	41	Bottom	41.1	79.0	0.91	2.2	64	0.45
										Bottom	42.1	78.1	0.93	2.9	54	0.46
	42	-23	Clay	7	31	62	67	25	42	Top	34.7	85.8	1.12	3.5	72	0.56
										Top	43.1	77.0	0.49	13.0	20	0.24
			Clay	10	23	67	73	27	46	Middle	59.4	63.2	0.30	7.0	16	0.15
										Middle	42.1	78.2	0.50	4.3	38	0.25
			Clay	6	24	70	82	32	50	Bottom	55.7	66.1	0.34	4.0	23	0.17
										Bottom	42.7	78.2	0.59	5.0	37	0.29
	44	-25	Clay	10	24	66	73	28	45	Top	35.4	84.1	1.07	5.2	58	0.53
										Top	32.0	86.2	1.09	5.2	68	0.52
			Clay	6	14	80	85	31	54	Middle	41.7	77.8	0.97	3.2	66	0.48
										Middle	44.7	75.8	0.89	3.0	66	0.44
			Clay	7	23	70	82	27	55	Bottom	44.7	75.8	0.85	5.0	53	0.42
										Bottom	42.9	76.3	1.08	3.6	75	0.54
	45	-26	Clay	8	19	73	89	29	60	Top	41.8	78.7	1.04	2.5	78	0.52
										Top	40.1	80.4	1.26	2.8	86	0.63
			Clay	10	29	61	71	27	44	Middle	37.8	81.9	1.22	4.0	78	0.61
										Middle	38.3	82.1	1.30	2.8	98	0.65
			Clay	8	38	54	65	25	40	Bottom	34.5	85.0	0.90	3.5	47	0.45
										Bottom	34.5	85.8	0.99	3.4	61	0.49
D-3-3	38	-11	Clay	--	--	--	--	--	--	Top	42.2	78.0	0.70	10.0	43	0.35
										Top	41.7	79.0	0.70	10.0	48	0.35
			Clay	--	--	--	--	--	--	Middle	49.8	71.0	0.58	5.8	40	0.29
										Middle	37.1	82.9	0.86	2.6	69	0.43
			Clay	--	--	--	--	--	--	Bottom	43.2	76.8	0.76	2.4	51	0.38
										Bottom	38.0	81.6	0.81	2.1	67	0.40

Table 3 (Contd)

CLASSIFICATION AND UNCONFINED COMPRESSION TEST DATA

Boring	Sample	Sample Elev msl	Classification	Mechanical Analysis % Sand	Mechanical Analysis % Silt	Mechanical Analysis % Clay	Atterberg Limits LL	Atterberg Limits PL	Atterberg Limits PI	Sample Section	Natural Water Content % Dry Wt	Dry Density Lb/Cu Ft	Max. Stress T/Sq Ft	Strain at Max. Stress %	Modulus of Deformation at 1% Strain T/Sq Ft	Cohesion c T/Sq Ft
D-3-3	39	-12	Clay	--	--	--	--	--	--	Top	38.7	80.2	0.47	1.4	44	0.23
										Top	39.2	79.7	0.55	1.5	44	0.27
			Clay	--	--	--	--	--	--	Middle	39.9	79.0	0.46	1.1	46	0.23
										Middle	39.8	79.7	0.47	1.1	46	0.23
			Clay	--	--	--	--	--	--	Bottom	43.5	76.3	0.45	1.0	45	0.22
										Bottom	42.9	76.8	0.55	1.3	52	0.27
	41	-14	Clay	--	--	--	--	--	--	Top	40.9	78.2	0.61	1.3	58	0.30
										Top	44.4	76.3	0.62	1.2	59	0.31
			Clay	--	--	--	--	--	--	Middle	38.2	78.0	0.55	1.5	44	0.27
										Middle	41.9	76.8	0.62	1.2	60	0.31
			Clay	--	--	--	--	--	--	Bottom	42.2	78.0	0.95	1.3	90	0.47
										Bottom	42.1	77.8	0.75	1.2	70	0.37
	42	-15	Clay	--	--	--	--	--	--	Top	37.6	79.9	0.93	2.0	72	0.46
										Middle	40.6	78.2	0.81	1.7	72	0.40
										Middle	39.7	77.5	0.73	1.5	64	0.36
			Clay	--	--	--	--	--	--	Bottom	40.4	77.3	0.56	1.7	40	0.28
										Bottom	42.8	75.8	0.59	1.7	40	0.29

Table 4

SUMMARY OF CONSOLIDATION DATA

Boring	Sample	Elev Ft msl	Classification	Atterberg Limits LL	PL	PI	Water Content % Dry Wt.	Density d Lb/Cu Ft	Condition of Sample	Initial Void Ratio e_o	Consolidation Coefficient C_c	Overburden Pressure P_o T/Sq Ft	Preconsolidation Pressure P_c T/Sq Ft	Type of Sampler	Inside Clearance %
D-3-1	2	28.5	Clay	73	26	47	39.0	85.0	Undisturbed	1.000	0.235	0.33	1.10	Vacuum	2.77
	9	17.2	Silty clay	35	12	23	32.9	86.0	Undisturbed	1.000	0.230	0.63	1.30	Vacuum	1.63
	11	12.2	Sandy silt	30	22	8	28.8	95.5	Undisturbed	0.768	0.160	0.36	1.60	Vacuum	1.42
	16C	0.2	Clay	75	27	48	44.8	76.6	Undisturbed	---	0.426	1.08	1.45	Vacuum	2.77
	D	0.2	Clay	86	26	60	44.8	75.3	Remolded	---	0.442	1.08	1.43	Vacuum	
	17-1	-1.8	Silty clay	--	--	--	39.0	82.5	Undisturbed	1.068	0.365	1.13	2.30	Vacuum	0.64
	-2		Silty clay	--	--	--	38.8	83.0	Undisturbed	1.055	0.375	1.13	2.30	Vacuum	
	19	-5.8	Clay	74	23	51	38.5	82.7	Undisturbed	1.072	0.376	1.24	2.70	Vacuum	1.42
	22	-11.8	Clay	70	23	47	39.0	86.3	Undisturbed	1.000	0.322	1.39	1.90	Vacuum	0.64
	23	-13.7	Clay	87	29	58	39.7	79.1	Undisturbed	1.134	0.418	1.45	2.90	Vacuum	2.77
	24	-16.3	Clay	61	28	33	36.6	84.1	Undisturbed	1.007	0.327	1.53	2.50	Vacuum	0.64
D-3-2	8	30.7	Clay	81	19	62	44.6	75.7	Undisturbed	1.263	0.493	0.33	1.70	5-in. piston	2.67
	12	24.2	Clay silt	46	22	24	27.8	93.8	Undisturbed	0.766	0.256	0.48	2.40	5-in. piston	2.67
	18	17.2	Silty clay	51	25	26	41.1	74.8	Undisturbed	1.290	0.395	0.68	2.30	5-in. piston	2.67
	31-1	-5.0	Clay	--	--	--	39.2	81.3	Undisturbed	1.098	0.402	1.26	2.90	5-in. piston	2.67
	-2		Clay	--	--	--	36.4	84.4	Undisturbed	1.022	0.374		2.60	5-in. piston	
	32-C & D	-6.0	Silty clay	60	23	37	36.2	84.5	Undisturbed	---	0.337	1.29	2.80	5-in. piston	2.67
							39.8	79.4	Remolded	---	0.342	1.29	0.58	5-in. piston	
	43	-23.7	Clay	70	25	45	37.9	82.5	Undisturbed	1.038	0.398	1.77	3.10	5-in. piston w/liner	1.48

Table 4 (Contd)

SUMMARY OF CONSOLIDATION DATA

Boring	Sample	Elev Ft msl	Classification	Atterberg Limits LL	PL	PI	Water Content % Dry Wt.	Density d Lb/Cu Ft	Condition of Sample	Initial Void Ratio e_o	Consolidation Coefficient C_c	Overburden Pressure P_o T/Sq Ft	Preconsolidation Pressure P_c T/Sq Ft	Type of Sampler	Inside Clearance %
D-3-3	31-1	-3.1	Clay	--	--	--	33.7	87.4	Undisturbed	0.957	0.330	1.31	2.30	5-in. piston w/liner	1.48
	-2			--	--	--	35.8	85.3	Undisturbed	0.909	0.330		2.50		
	32-C	-4.1	Clay	79	27	52	41.6	78.4	Undisturbed	---	0.422	1.34	2.03	5-in. piston w/liner	1.48
	-D		Clay	74	27	47	40.5	78.4	Remolded	---	0.395	1.34	1.50		
	40	-13.3	Clay	70	33	37	39.5	81.5	Undisturbed	1.072	0.676	1.57	3.70	5-in. piston w/liner	1.91
	44	-17.4	Clay	70	28	42	35.9	84.4	Undisturbed	1.000	0.392	1.69	3.60	5-in. piston w/liner	2.67

Table 5

UNCONFINED COMPRESSION TEST DATA
COMPARISON OF UNDISTURBED AND REMOLDED SAMPLES

				Mechanical Analysis			Atterberg Limits						Unconfined Compression Test Data					
Boring	(1) Sample	Sample Elev msl	Classification	% Sand	% Silt	% Clay	LL	PL	PI	Water Content % Dry Wt.	Dry Density Lb/Cu Ft	Condition of Sample	Max. Stress T/Sq Ft	Strain at Max. Stress %	Modulus of Deformation at 1% Strain T/Sq Ft	Cohesion c_c T/Sq Ft	Average (2) Max. Stress T/Sq Ft	(3) Sensitivity Ratio
D-3-1	16A	0.02	Clay	9	28	53	80	23	57	41.4	77.9	Undist.	0.63	13.5	26	0.32	--	--
										37.4	81.5	Undist.	0.71	6.1	31	0.36	--	--
										48.1	70.2	Undist.	0.47	14.5	20	0.24	0.60	--
										45.2	73.5	Remolded	0.64	13.3	27	0.32	--	--
										42.5	75.2	Remolded	0.74	19.4	19	0.37	0.69	0.87
	16B		Clay	9	25	66	84	23	61	52.3	67.9	Undist.	0.39	21.2	21	0.20	--	--
										43.9	75.0	Undist.	0.54	13.9	30	0.27	--	--
										40.7	78.2	Undist.	0.76	7.4	41	0.38	0.56	--
										45.8	73.2	Remolded	0.44	25.4	19	0.22	--	--
										45.1	73.8	Remolded	0.56	24.0	21	0.28	0.50	1.12
D-3-2	32A	-6.0	Clay	8	23	69	78	25	53	39.9	79.2	Undist.	0.87	2.9	55	0.44	--	--
										38.9	80.2	Undist.	0.92	3.1	55	0.46	--	--
										40.2	79.1	Undist.	0.74	3.4	55	0.37	0.84	--
										40.2	78.1	Remolded	0.84	13.9	19	0.42	--	--
										39.5	78.9	Remolded	1.03	13.4	34	0.52	0.93	0.90
	32B		Clay	--	--	--	--	--	--	36.2	83.1	Undist.	0.86	6.4	43	0.43	--	--
										35.2	84.1	Undist.	0.93	7.8	45	0.47	--	--
										37.3	81.7	Undist.	0.76	5.8	46	0.38	0.85	--
										34.9	83.6	Remolded	0.97	18.8	20	0.49	--	--
										35.3	83.0	Remolded	0.98	23.2	33	0.49	0.97	0.88
D-3-3	32A	-4.1	Clay	12	28	60	78	24	54	39.7	77.3	Undist.	0.57	2.2	38	0.29	--	--
										37.6	79.0	Undist.	0.64	3.1	51	0.32	--	--
										38.1	78.1	Undist.	0.59	2.2	35	0.30	0.60	--
										38.3	79.9	Remolded	0.79	25.1	11	0.40	--	--
										38.4	79.9	Remolded	0.94	14.0	18	0.47	0.86	0.70
D-3-3	32B		Clay	7	26	67	81	25	56	41.5	75.9	Undist.	0.52	2.2	42	0.26	--	--
										40.4	74.6	Undist.	0.21	2.3	20	0.11	--	--
										41.1	76.0	Undist.	0.66	2.9	46	0.33	0.59*	--
										37.5	81.4	Remolded	0.95	13.4	22	0.48	--	--
										41.0	77.0	Remolded	1.01	23.[illegible]	41	0.51	0.98	0.60

Notes: (1) "A" and "B" denote top quarter and second quarter from top of sample, respectively.
(2) Values shown are average of three undisturbed or two remolded specimens.
* Omitting value of 0.21 tons per sq ft.

(3) Degree of sensitivity = $\frac{\text{Unconfined compressive strength undisturbed}}{\text{Unconfined compressive strength remolded}}$.